

High Repetition Rate Pulsed 2-Micron Laser Transmitter for Coherent CO₂ DIAL Measurement

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Abstract: A high repetition rate, highly efficient, Q-switched 2-micron laser system as the transmitter of a coherent differential absorption lidar for CO₂ measurement has been developed at NASA Langley Research Center. Such a laser transmitter is a master-slave laser system. The master laser operates in a single frequency, either on-line or off-line of a selected CO₂ absorption line. The slave laser is a Q-switched ring-cavity Ho:YLF laser which is pumped by a Tm: fiber laser. The repetition rate can be adjusted from a few hundred Hz to 10 kHz. The injection seeding success rate is from 99.4% to 99.95%. For 1 kHz operation, the output pulse energy is 5.5mJ with the pulse length of ~50 ns. The optical-to-optical efficiency is 39% when the pump power is 14.5W. The measured standard deviation of the laser frequency jitter is about 3 MHz.

1. Introduction

Carbon dioxide (CO₂) has been recognized as one of the most important greenhouse gases. It is essential for the study of global warming to accurately measure the CO₂ concentration in the atmosphere and continuously record its variation. A Ho:YLF laser operating in the range of 2.05 μm can be tuned over several characteristic lines of CO₂ absorption. Recently, a diode pumped Ho:Tm:YLF laser has been successfully used as the transmitter of coherent differential absorption lidar for the measurement of CO₂ with a repetition rate of 5 Hz and pulse energy of 75 mJ [1]. For coherent detection, high repetition rate is required for speckle averaging to obtain highly precise measurements [2]. However, a diode pumped Ho:Tm:YLF laser can not operate in high repetition rate due to the large heat loading and up-conversion. A Tm: fiber laser pumped Ho:YLF laser with low heat loading can operate in high repetition rate.

A theoretical model has been established to simulate the performance of Tm: fiber laser pumped Ho:YLF lasers. For continuous wave (CW) operation, high pump intensity with small beam size is suitable for high efficiency. For Q-switched operation, the optimal energy extraction relies on the pump intensity, pump volume, and pump duration which is inversely proportion to the repetition rate. CW and Q-switched Ho:YLF lasers with different linear cavity configurations have been designed and demonstrated for a 30 W Tm: fiber pump laser [3, 4]. The CW Ho laser slope efficiency and optical-to-optical efficiencies reach 65% and 55%, respectively. The pulsed laser efficiency depends on the repetition rate. For 1 KHz operation, the optical-to-optical efficiency is 39% when the pump power is 14.5W. Currently, the injection seeding success rate is between 99.4% and 99.95% [5, 6]. After a ten thousand pulses, the standard deviation of the laser frequency jitter is about 3 MHz. It meets the requirements of highly precise CO₂ concentration measurement.

In order to avoid spectral hole burning and make injection seeding easier, a four mirror ring cavity is designed for the high repetition rate and single frequency Ho:YLF laser.

2. Experiment

Figure 1 shows the experimental setup. The laser system is in a master-slave configuration to obtain single longitudinal mode operation. The master laser, also called seed laser, is a CW single frequency Ho:Tm:YLF laser. The slave laser is a Q-switched Ho:YLF laser in a four-mirror ring-cavity configuration which is end-pumped by a Tm: fiber laser. The maximum output power of the Tm: fiber laser is 40W at the random polarization. Only 15W of pump power reaches the laser crystals along the π -polarization. In order to avoid damage to laser crystal, there are two laser crystals in the slave laser. The pump beam passes through a low doping concentration crystal first and then the high doping concentration one. The optimal repetition rate of the designed slave laser is 1 kHz, considering the speed of data

The laser system encounters a Q-switch hold-off problem at the operation rate lower than 1kHz, when the pump power from Tm: fiber laser reaches maximum. To improve the hold-off, two cascaded Q-switchers are inserted into the ring cavity. The output pulse energy is 9.3mJ at 500Hz operation when the pump power measured by detector D_1 is 14.14W. For 100 Hz operation, the output pulse energy can reach 30.8 mJ where the pump power measured by detector D_1 is 12.86W

Fig.3 shows the optical-to-optical efficiency at the different repetition rates. The optical-to-optical efficiency increases with the repetition rate. The maximum optical-to-optical efficiency for Q-switching mode approaches the CW optical-to-optical efficiency of 47%. The optimal repetition rate corresponds to the turning point of optical-to-optical efficiency curve. It is close to 1 kHz as shown in Figure 3. The optical-to-optical efficiency at a 1 kHz repetition rate is 39%.

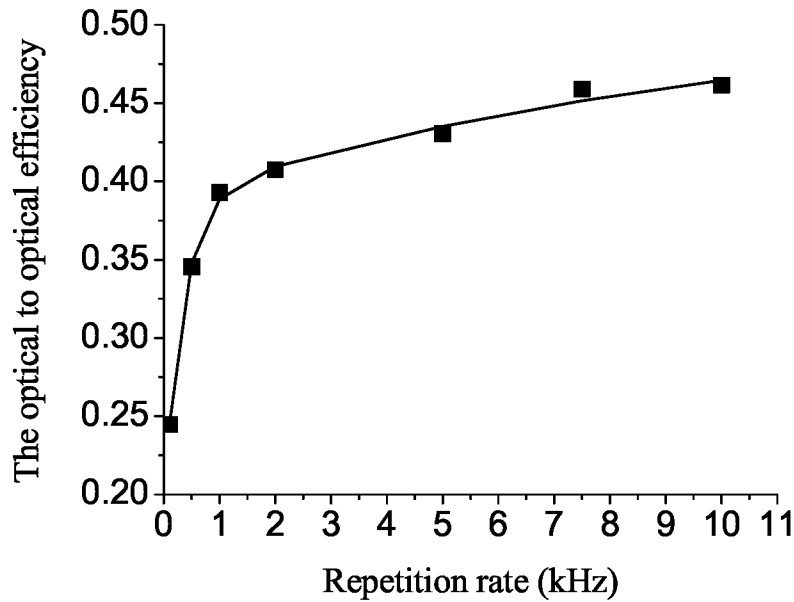


Fig.3. Optical-to-optical efficiency versus repetition rate

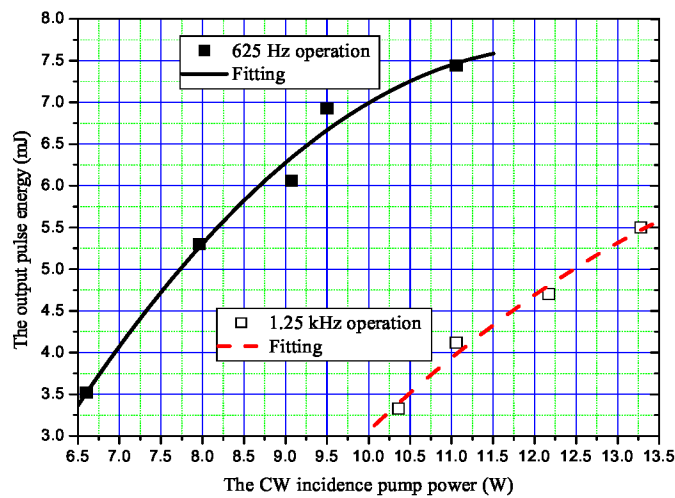


Fig.4. Output pulse energy versus incident pump power at different repetition rates

Fig.4 shows the laser performances for 625 Hz and 1.25 kHz operations. For 625Hz operation, the optical to optical efficiency can reach more than 40%; the pulse length is between 40nS and 60nS; and the seeding success rate is from 98% to 99.8%. For 1.25 kHz operation, the optical to optical efficiency can reach more than 50%; the pulse length is between 45nS and 60nS; and the seeding success rate is from 99.4% to 99.95%.

In order to measure the line width and frequency jitter deviation, an acoustic-optical modulator is inserted between the master laser and slave laser to modulate seeding wavelength. The frequency beating between laser pulse from the slave laser and non modulated CW beam from the master laser gives the information of pulse line width and frequency jitter deviation. At 500 Hz operation, the standard deviation of laser frequency jitter is less than 3 MHz after a ten thousand pulses.

4. Conclusion

An injection seeded, high repetition rate, Q-switched Ho:YLF laser has been developed for a coherent CO₂ differential absorption lidar. This master-slave laser system has high optical-to-optical efficiency and seeding success rate. It can potentially meet the requirements of the coherent detection of CO₂ concentration by a differential absorption lidar technique.

5. Acknowledgement

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6. References

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